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(54) RARE EARTH PERMANENT MAGNET MACHINES

(71) We, KOLLMORGEN TECHNOLOGIES CORPORATION of Republic National Bank Building, Dallas, Texas 75201, a corporation duly organized and existing under the laws of the State of Texas, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The present invention relates to permanent magnet machines and, more particularly, permanent magnet machines which employ rare earth permanent magnets. The rare earth permanent magnets are preferably formed from a cobalt-rare earth magnet material. Because of their superior performance capabilities, rare earth permanent magnets have been used in permanent magnet machines in place of conventional permanent magnets, such as Alnico permanent magnets. The substantially higher cost of rare earth permanent magnets, however, makes their use in many applications economically impractical.

The present invention solves that problem by developing rare earth permanent magnet machines, such as D.C. motors, A.C. synchronous motors and alternators, and step motors which use only one-half the rare earth permanent magnet material normally employed and yet develop approximately eighty percent of the performance of machines using the full complement of rare earth permanent magnet material. This results in considerable cost savings at a modest, and in many cases, inconsequential reduction in performance.

In accordance with the present invention, instead of forming all poles from rare earth permanent magnets, only one-half of the poles are formed from rare earth permanent magnets, the remaining poles comprising iron and not including rare earth permanent magnets. While the consequent pole concept is not itself new, having been used in multi-pole induction motors with special stator windings which allow these motors to operate at one-half normal speed, there is no suggestion that a pole design could be developed which would permit rare earth permanent magnet machines to achieve approximately eight percent of the performance of a conventional otherwise comparable, maching using the full complement of rare earth permanent magnet material while employing only one-half that amount of permanent magnet material.

The permanent magnet machine of this invention comprises a multi-pole rotor; and a multi-pole stator, with one-half of the poles of the rotor or of the stator comprising rare earth permanent magnets and the remainder of said poles of the stator or the rotor comprising iron and not including rare earth permanent magnets.

In addition, the use of the pole design of this invention in connection with rare earth permanent motors permits effective field control using field windings on the poles not including some rare earth magnets. To obtain field control for a conventional rare earth permanent magnet motor employing a full complement of rare earth permanent magnet material would require a very large number of ampere turns to force the flux through the rare earth permanent magnets, which act as large air gaps.

The invention herein is described in connection with the drawings which accompany the specification wherein:

Figure 1 is a view in section of a field control rare earth permanent magnet D.C. motor or D.C. generator in accordance with the present invention;

Figure 2 is a view in section of a conventional rare earth permanent magnet D.C. motor or D.C. generator having a wound rotor;

Figure 3 is a view in section of a consequent pole rare earth permanent magnet D.C. motor or D.C. generator having a wound rotor;

Figure 4 is a view in section of a conventional rare earth permanent magnet A.C. alternator or step motor or inside-out D.C. motor using electronic commutation; and

Figure 5 is a view in section of a consequent pole rare earth permanent magnet A.C. alternator or step motor or inside-out D.C. motor using electronic commutation.

Referring now to Figure 1, there is shown a field control rare earth permanent D.C. motor or D.C. generator 10 in accordance with the present invention. It comprises an iron stator 11 having poles 12, 13, 14 and 15. Poles 12 and 14 have field windings 16 and 17 associated therewith. Pole 13 has rare earth permanent magnets 18*a* and 18*b* associated therewith while pole 15 has rare earth permanent magnets 19*a* and 19*b* associated therewith. Machine 10 also has a rotor 20 which is a conventional wound rotor, the windings of which are energized by a D.C. source for a motor or connected to a load for a generator through a commutating structure which is not shown for purposes of simplicity.

Earlier attempts to get field control in a machine having rare earth permanent magnets indicated that a very large number of ampere turns would be required because the field winding had to force the flux through the rare earth permanent magnets which acted as very large air gaps. By employing the pole design of the present invention, however, it has been found practical to obtain field control in a machine having rare earth permanent magnets included in one-half of the stator poles. Thus, as shown in Figure 1, every other pole has rare earth permanent magnets associated therewith while the poles not including rare earth magnets are wound with field windings. The center sections of these poles provide paths for the flux generated by the wound field.

Referring now to Figure 2 there is shown a conventional rare earth permanent magnet D.C. motor or D.C. generator 30 having a wound rotor. The machine comprises an iron stator 31 having four poles formed by four groups of rare earth magnets 32 through 35. Machine 30 has a conventional wound armature 36 which is energized by a source of D.C. power for a motor or connected to a load for a generator through a commutating structure which is not shown for purposes of simplicity.

Figure 3 shows a consequent pole rare earth magnet D.C. motor or D.C. generator 40 in accordance with the present invention. Machine 40 comprises an iron stator 41 having two poles formed from rare earth magnets 42 and 43 and two consequent poles 44 and 45 formed from iron. Machine 40 has conventional wound armature which is the same as the armature of machine 30 and bears the same reference numeral, i.e., 36.

As just brought out, machines 30 and 40 are otherwise the same except that conventional machine 30 has a full complement of rare earth permanent magnet material whereas machine 40 of this invention has a consequent pole stator which employs one-half the rare earth permanent magnet material used in machine 30. One would expect that since machine 40 uses one-half the rare earth permanent magnet material used in machine 30, the performance of machine 40 would be one-half the performance of machine 30. That, however, has not been found to be true. Rather, tests have unexpectedly shown that the performance of machine 40 is only twenty percent (20%) less than that of machine 30.

The important parameter in evaluating motor performance is the torque sensitivity of the motor. A D.C. motor built to the configuration of machine 30 developed approximately 40 inch ounces per ampere while one built in the configuration of machine 40, with only one-half the rare earth permanent magnet material, developed a torque sensitivity of 32 inch ounces per ampere, a truly unexpected result. Moreover, the decrease by one-half in the amount of rare earth permanent magnet material represents a considerable savings in material costs.

Referring now to Figure 4 there is shown a conventional rare earth permanent magnet A.C. alternator, step motor of D.C. motor 50 using electronic commutation. Machine 50 has a rotor which comprises an iron rotor core 51 having affixed thereto four poles formed by four rare earth permanent magnets 52 through 55. Machine 50 also has a stator which comprises four iron pole pieces 56 through 59 having windings 60 through 63 associated respectively therewith.

Figure 5 shows a consequent pole rare earth permanent magnet A.C. alternator, step motor or D.C. motor 70 using electronic commutation in accordance with the present invention. Machine 70 has a rotor which comprises an iron rotor core 71 from which are formed two iron poles 72 and 73. Two other poles are formed from two rare earth permanent magnets 74 and 75 which are affixed to core 71. Machine 70 has a conventional stator which is the same as the stator of machine 50. It comprises four iron pole pieces 56 through 59 having windings 60 through 63 associated respectively therewith.

As just noted machines 50 and 70 are otherwise the same except that machine 50

has a rotor with a full complement of rare earth permanent magnet material while machine 70 has a consequent pole rotor which employs one-half the rare earth permanent magnet material used in machine 50. One would expect that since machine 70 uses one-half the rare earth permanent magnet material used in machine 50 the performance of machine 70 would be one-half the performance of machine 50. Such, however, is not the case. Tests have unexpectedly shown that the performance of machine 70 is only sixteen percent (16%) less than that of machine 50.

The important parameter in evaluating alternator performance is the voltage developed at the load. Alternator 50 feeding into a resistive load through a bridge rectifier had a D.C. load current of 5.3 amperes and an output of 20.4 volts D.C. while alternator 70, with only one-half the rare earth permanent magnet material, produced an output of 17.1 volts D.C. for the same load current, a truly unexpected result. Moreover, the decrease by one-half in the amount of rare earth permanent magnet material required represents a considerable reduction in material costs.

The invention is not limited to the specific exemplary embodiments disclosed herein since modifications undoubtedly occur to those skilled in the art.

WHAT WE CLAIM IS:-

1. A permanent magnet machine comprising:

a multi-pole rotor; and

a multi-pole stator

with one half of the poles of the rotor or the stator comprising rare earth permanent magnets and the remainder of said poles of the stator or the rotor comprising iron and not including rare earth permanent magnets.

2. The machine of Claim 1, wherein the rotor or the stator has at least two poles comprising rare earth permanent magnets and at least two poles comprising iron pole pieces; and the stator or the rotor comprises at least 4 poles.

3. The machine of Claim 1 or Claim 2 wherein the rotor comprises a multi-pole wound armature; and the stator comprises iron pole pieces, one half of said iron pole pieces having rare earth permanent magnets associated therewith and the remainder of said pole pieces having field windings associated therewith for providing field control for said machine.

4. The machine of at least one of the Claims 1 through 3, wherein the rotor is provided with a multi-pole wound armature adapted for connection to a source of D.C. power; and serving as a rare earth permanent magnet D.C. motor.

5. The machine of at least one of the Claims 1 through 3, wherein the rotor is provided with a multi-pole wound armature adapted for connection to a load; and serving as a D.C. generator with field control.

6. The rare earth permanent magnet motor of Claim 4, said motor being capable of developing a torque sensitivity which is substantially greater than one-half the torque sensitivity of a conventional, otherwise comparable, motor wherein all of the stator poles comprise rare earth permanent magnets.

7. The motor of Claim 6 wherein the motor is capable of developing at least 75% of the torque sensitivity of said otherwise comparable motor.

8. The machine of Claim 1 or Claim 2 wherein the multi-pole stator comprises a plurality of iron pole pieces, each pole piece having a winding associated therewith, said windings being adapted for connection to a source of electric power; and wherein the multi-pole rotor is adapted to rotate within said stator, one-half of the poles of said rotor comprising rare earth permanent magnets and the remained of said rotor poles comprising iron pole pieces.

9. The machine of Claim 1 or Claim 2 wherein the multi-pole stator comprises a plurality of iron pole pieces, each pole piece having a winding associated therewith, said windings being adapted for connection to a source of power; and the multi-pole rotor is adapted to rotate within said stator, one-half the poles of said rotor comprising rare earth permanent magnets and the remainder of said rotor poles comprising iron pole pieces; said machine serving as a rare earth permanent magnet A.C. alternator.

10. The machine of Claim 1 or Claim 2 wherein the multi-pole stator comprises at least four iron pole pieces, each pole piece having a winding associated therewith, said windings being adapted for connection to a source of power; and the multi-pole rotor is adapted to rotate within said stator and is provided with at least four poles, one-half of said rotor-poles comprising rare earth permanent magnets and the remainder of said rotor-poles comprising iron pole pieces; said machine serving as an A.C. alternator being capable of developing a rectified D.C. output voltage at a D.C. load current which is substantially greater than one-half of the rectified D.C. output voltage at the same load current developed by a conventional otherwise comparable, A.C. alternator wherein all of the rotor poles comprise rare earth permanent magnets.

11. The A.C. alternator of Claim 10 wherein said alternator is capable of developing at least 75% of the rectified D.C. output voltage of said otherwise comparable alternator.

For and on behalf of
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CORPORATION
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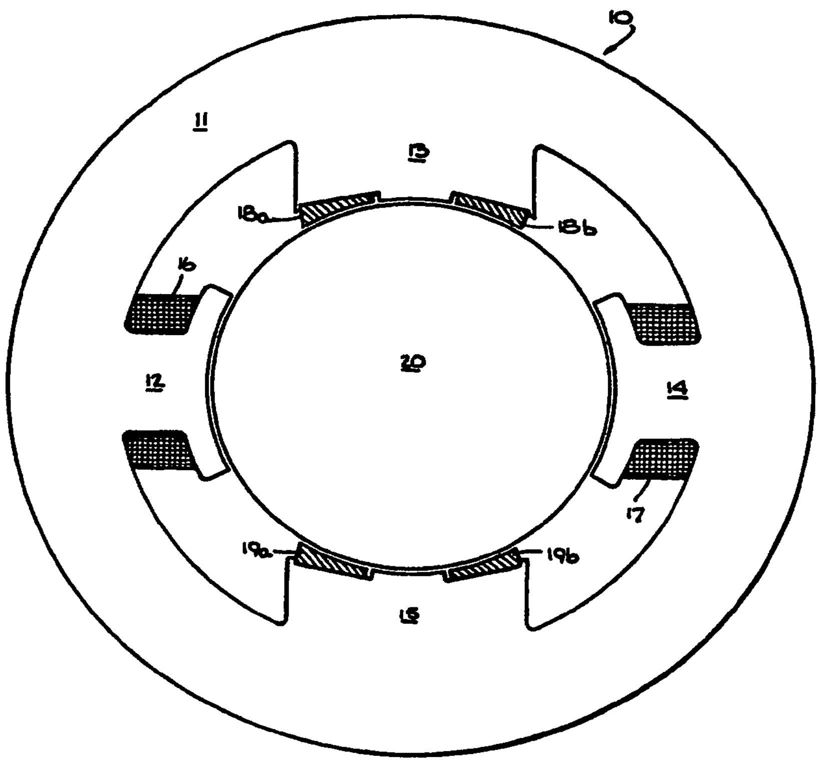


Fig.1.

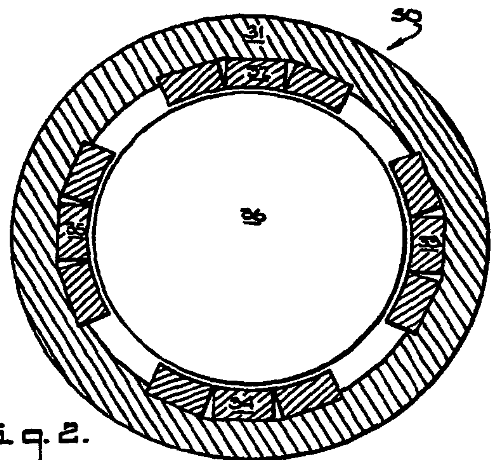
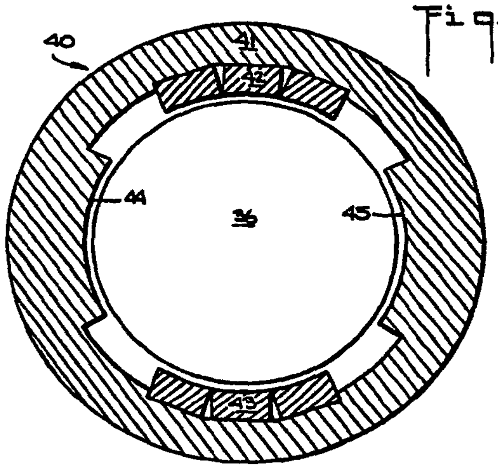


Fig. 2.

Fig. 3.



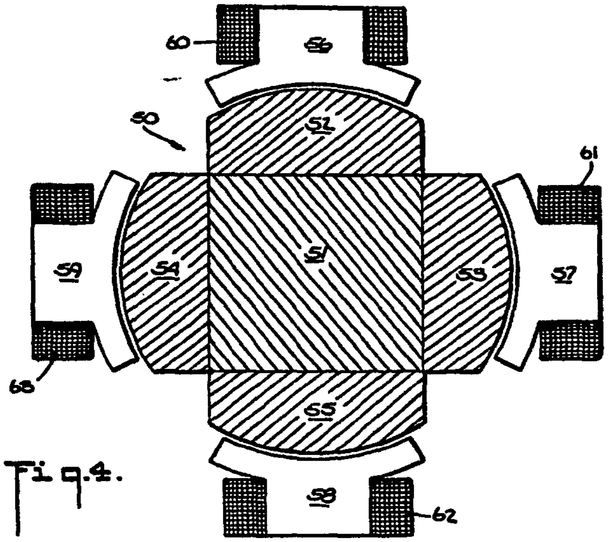

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Fig.4.

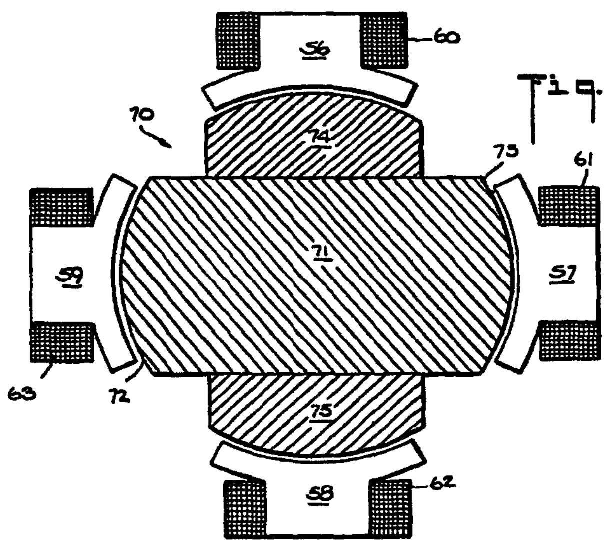
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Fig.5.